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# Biodiesel produced by waste cooking oil: Review of recycling modes in China, the US and Japan

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ABSTRACT

Waste cooking oil to biodiesel conversion efficiency depends on the recycling mode that is being practiced. The recycling modes in China, the US and Japan can be placed in two categories: third party take-back (TPT) and the biodiesel enterprise take-back (BET). We review the operation mechanisms of theses modes, their advantages and disadvantages in three countries and compare them using recycling costs and profits of biodiesel enterprises, subsidies for manufacturers, recycling rates, degree of administrative control, technical support and incentive mechanisms provided for the restaurants. We find that the TPT mode practiced in Japan and the US is superior to the BET mode due to the subsidies provided for biodiesel enterprises and the implementation of strict regulation policies in place for the restaurants. In China, Suzhou and Ningbo cases may have better resource recovery effect than the TPT mode practiced elsewhere, if further enhanced. Finally, we provide suggestions for improving waste oil to biodiesel conversion in China.



**Contents**



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## 1. Introduction

Food safety concerns have been attracting some attention in China recently. Especially, use of reprocessed waste cooking oil (commonly known as gutter oil) in restaurants and elsewhere seems to be a growing problem. This practice continues despite control measures adopted by the government. It is estimated that over five million tons of waste cooking oil is generated in the urban restaurant industry in China, of which 40–60 percent backflow to dining tables through various channels [1]. Thus, devising implementation strategies to safeguard waste cooking oil management becomes of utmost importance in food safety.

One possible strategy may be to incentivize use of waste cooking oil for power production. Clean energy continues to play an important role in power production and sustainable development. For instance, waste cooking oil has become an important source in biodiesel production. Furthermore, in China, *the Twelfth Five-year Plan for Renewable Energy Development* (*2012*) and *the Twelfth Five-year Plan for Bioenergy Development* (*2012*) were introduced in order to set the focus for development of bioenergy for the foreseeable future. Developed economies such as Japan, the Netherlands and the US have already realized the benefits of recycling of waste cooking oil and this resource is being successfully reused in the transportation industry.

Conversion of waste cooking oil to biodiesel can accomplish two goals: enhancement of public food safety and an increase in power produced via renewable energy. To this effect, the Chinese government began placing more emphasis on waste cooking oil management through "targets planning", development of regulations, and improvement of the overall recycling system. In recent years, China also began supporting resource recovery and harmless disposal throughout the country by establishing special funds and conducting experiments in 33 cities [2].

In contrast, developed countries such as Japan and the US, began adopting policies dealing with waste cooking oil to energy conversion much earlier. For instance, the US has promulgated *Solid Waste Disposal Act* (*1960*), *Pollution Prevention Act of 1990* and *Energy Policy Act* (*2005*) to implement strict controls on resource recovery. Moreover, the US has developed price subsidy policies to stimulate sale of biodiesel. For instance, a subsidy of 50 cents/gallon of biodiesel produced by recycled oil is offered in the US. Japan has similar policies in place. In order to promote recycling of waste cooking oil, Japanese government has issued and amended the *Promotion Law on Effective Utilization of Resources* (*2000*), and *the Act of Food Waste Recycling* (*2001*) successively and provides support using raw material price subsidies and sales tax incentives.

Although the technology to produce biodiesel via waste cooking oil is well developed, there are other factors constraining the growth of waste oil refining industry in China, e.g. lack of raw materials and supportive policies. Clearly, recycling modes that are in place in a region contribute to the availability of raw materials for the waste oil refining industry. The modes are shaped by government regulation and/or incentives provided, and both of which have a direct impact on the recycling rates and profitability of biodiesel enterprises. Hence, selection and successful implementation of an appropriate recycling mode can benefit the waste cooking oil to biodiesel conversion. In practice, China has two recycling modes in place for waste cooking oil recovery. In this paper, a comparative review of recycling modes in China, the US, and Japan is presented, which can potentially benefit the Chinese government in adjusting its policies for waste cooking oil management and consequently promote biodiesel production.

## 2. Literature review

Most of the studies on recycling modes focus on waste electronic appliances recovery and they can be grouped in two broad areas, namely, selection and evaluation of recycling modes in reverse logistics, and operation and management of recycling modes.

### 2.1. Selection and evaluation of recycling modes in reverse logistics

There are three types of well-defined recycling modes, third party take-back (TPT), retailer take-back (RT) and manufacturer take-back (MT). There are a number of studies that have compared these modes using various metrics such as profits generated and recycling rates. For instance, Savaskan et al. and Savaskan and Van Wassenhove analyze recycling channel selection of manufacturers in closed loop supply chains and evaluate each recycling mode by calculating wholesale prices, retail prices, recycling rates and profits [3,4]. Liu et al. applies network analysis for recycling modes selection process and proposes an analytic network process based evaluation selection model considering a variety of perspectives such as economic, societal and technological [5]. Xu and Wu investigate the optimal direct selling price, retail price and recycling rate of each recycling mode by constructing a bi-level programming model [6]. Wei and Li compare recycling modes of MT, pooled take-back (PT) and TPT under the constraints of extended producer responsibility. In their comparative analysis, the optimal retail price and the manufacturers' profits among different recycling modes are explored [7]. Senthil et al. employ a similarity order preference model, using the analytic hierarchy process (AHP) and fuzzy environment to compare TPT, MT and joint take-back modes [8].

### 2.2. The operation and management of recycling modes

Majumder and Groenevelt analyze recovery of the end-of-life products by third party logistics providers [9]. Cheng and Lee, Azadi et al. and Govindan et al. discuss feasibility of outsourcing of the third party logistics services [10] and supplier evaluation, respectively [11,12]; Wang and Chen focus on remanufacturing policy under extended producer responsibility [13]; Johnson and McCarthy investigate developing an optimal recycling plan under extended producer responsibility [14].

The influence of government monitoring and subsidies on profits for the supply chain has also been extensively studied. For instance, Tsay analyzes impact of recycling contracts and price subsidy mechanisms under the retailer recycling mode [15]; Zhou and Wang review and evaluate three recycling modes for government monitoring [16]. Setting the reward and punishment mechanisms of the government as constraints, Wang and Da explore profits, recycling price and recycling rates for the recovery supply chain [17,18].

Although considerable work concerning recycling modes of waste products has been completed, there remain gaps in the literature. Review of recycling modes for waste cooking oil to biodiesel conversion is scarce. Existing studies concerning reverse supply chain of waste cooking oil mainly focus on problems regarding recycling modes of kitchen waste [19], reverse logistics management models [20], route planning for collection of waste cooking oil [21], economics and assessment of productive efficiency of refining biodiesel from waste cooking oil [22,23], optimization and distribution of the reverse supply chain [24], subsidies and regulation policies for the waste cooking oil to biodiesel conversion [25–27] and impact of subsidy policies on the profitability of biodiesel producers and the recyclers under the recycler take-back modes [28]. However, so far, there are no studies comparing recycling modes of multiple countries, especially one that includes China.

Albeit, some aspects of waste cooking oil to biodiesel recycling modes are identical with those of waste electronic products, there is significant heterogeneity in the parties involved, government

fees and subsidy mechanism for the former. Therefore, in this paper we compare recycling modes practiced in China, the US and Japan in handling waste cooking oil.

## 3. Heterogeneity in waste cooking oil to biodiesel conversion management

Analyzing the heterogeneity that exists in handling of waste cooking oil to biodiesel conversion is helpful in understanding the characteristics of the supply chain operation and the classification of different recycling models. Generally, stakeholders of recycling of waste electronic products include the government, remanufacturers, retailers, third party providers and consumers. The government develops policies to stimulate and/or regulate remanufacturers or consumers. Remanufacturers can choose to manufacture utilizing new materials or recycled waste products. Recycling of waste products is completed by remanufacturers, retailers or third party providers. Apart from recycling the waste products, retailers also obtain finished products from the manufacturers at the wholesale price and sell them to the consumers.

In contrast, waste cooking oil to biodiesel conversion has the following stakeholders: the government; biodiesel enterprises; third party providers; illegal manufacturers and restaurants. The government sets policies for the restaurants or the biodiesel enterprises and it also determines the waste disposal fee collection policies for the restaurants. Biodiesel enterprises may entrust third party providers in recycling the waste oil produced by the restaurants or do it themselves, and thereby produce finished products by refining the waste oil. The collectors of waste cooking oil assume no responsibilities of retailing the finished goods, which is not the case for waste electronic products. Furthermore, even though consumers that discard waste electronic products are not regulated, restaurants that discard the waste oil may be held responsible and strictly regulated by the government. Finally, illegal manufacturers cannot be ignored since their presence, which is stimulated by poor control and "interest guidance mechanism", allows waste cooking oil to flow towards them, thus disrupting the raw material supply for the legal enterprises.

There are also differences between the fees and subsidies mechanisms of the two supply chains. The government neither collects any fees nor develops any penalty policies on the consumers upstream of the supply chain of the recycling of waste electronic products. And, the goal of government's subsidy policy is to increase the recycling rate of remanufacturers. However, for waste cooking oil to biodiesel conversion, the government may implement strict penalty policy for the restaurants upstream of the recycling supply chain and require them to pay garbage disposal fees. The government also provides subsidies for the biodiesel enterprises or recyclers. The subsidies for the former are in place to reduce production costs and increase price competitiveness. The funds dispensed for the recyclers are burden for the government unless they are funded by garbage disposal fees charged to the restaurants. Table 1 presents the primary differences between the supply chains of waste cooking oil to biodiesel conversion and remanufacturing of waste electronic products.

## 4. Comparison of recycling modes

Recycling modes of waste cooking oil to biodiesel conversion can be classified in two categories, namely, the biodiesel enterprise take-back (BET) and the third party take-back (TPT). For the former, the biodiesel enterprises recycle the waste cooking oil collected or request internalized recyclers to purchase the waste oil. With the BET mode, it is necessary for the biodiesel enterprises to invest in, operate and manage the logistics network and facilities themselves. For the latter mode, biodiesel enterprises and recyclers are separate entities, which mean that the biodiesel enterprises outsource the recycling operation to a third party.

In this paper we explore four cases in practice in China where these two different modes are utilized. In three of these cases, namely, Suzhou case, Ningbo case and Lanzhou case, the biodiesel enterprises are responsible for recycling. Nanjing in China adopts the TPT mode which is also prevalently used in Japan and the US (see Fig. 1). TPT mode used in Nanjing is the most widely used mode in China.

### 4.1. The BET mode

#### 4.1.1. The Suzhou case

In the Suzhou case, collection, storage and transportation activities are integrated. In other words, there are no independent recyclers. The biodiesel enterprises (or the resource recovery enterprises) employ recycling vendors to collect waste cooking oil from the restaurants (see Fig. 2).

There are some distinguishing characteristics of the Suzhou case. First characteristic is the level of involvement of the government. The government in Suzhou aims to reduce the likelihood of waste oil being purchased by illegal manufacturers. To this end, they crack down on illegal manufacturers by confiscating illegal vehicles and intercepting illegal waste oil transportation, which reduces the possibility of backflow of waste oil to be reused in restaurants. This, to some extent, forces restaurants in employing the biodiesel enterprises.

Secondly, the biodiesel enterprises take measures to prevent loss of raw material in transportation and thereby increase profits. In Suzhou, they generally equip vehicles collecting the waste cooking oil with GPS devices. If the vehicles deviate from the predetermined route, the companies can investigate it; and employees who privately sell the gutter oil can be laid off. In addition, the production process of the enterprises is video monitored by the Suzhou Environmental Health Management Monitoring Center. Furthermore, installation of a weighing system in the recycling vehicles allows collection of information regarding waste cooking oil being transported by the vehicles. If the volume

**Table 1**
Heterogeneity of waste cooking oil to biodiesel conversion.

| | Stakeholders | Differences in the responsibilities of stakeholders | Fee and subsidy mechanism |
|---|---|---|---|
| Remanufacturing of waste electronic products | Government, remanufacturers, retailers, third party providers and consumers. | The remanufacturers produce the finished products with new materials or waste; the retailers may collect the waste and sell the finished products to the consumers at the wholesale price as well. | The government does not collect fees from or punish the consumers upstream of the supply chain. The subsidy target is to improve recycling rate. |
| Waste cooking oil to biodiesel conversion | Government, biodiesel manufacturers, third party providers, illegal manufacturers and restaurants. | The biodiesel enterprises produce the finished products with the waste cooking oil rather than new materials. The recyclers just collect the waste cooking oil. | The government may collect fees from or punish the restaurants upstream of the supply chain; the subsidy target is to reduce the production cost or increase the recycling rate. |

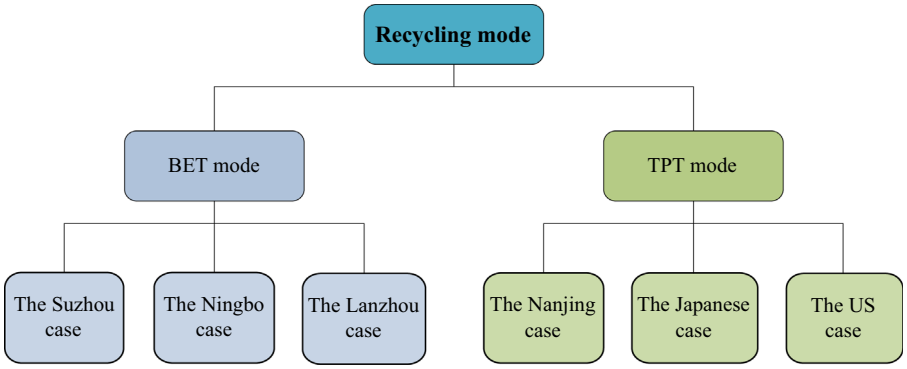


**Fig. 1.** Classification of the recycling modes.

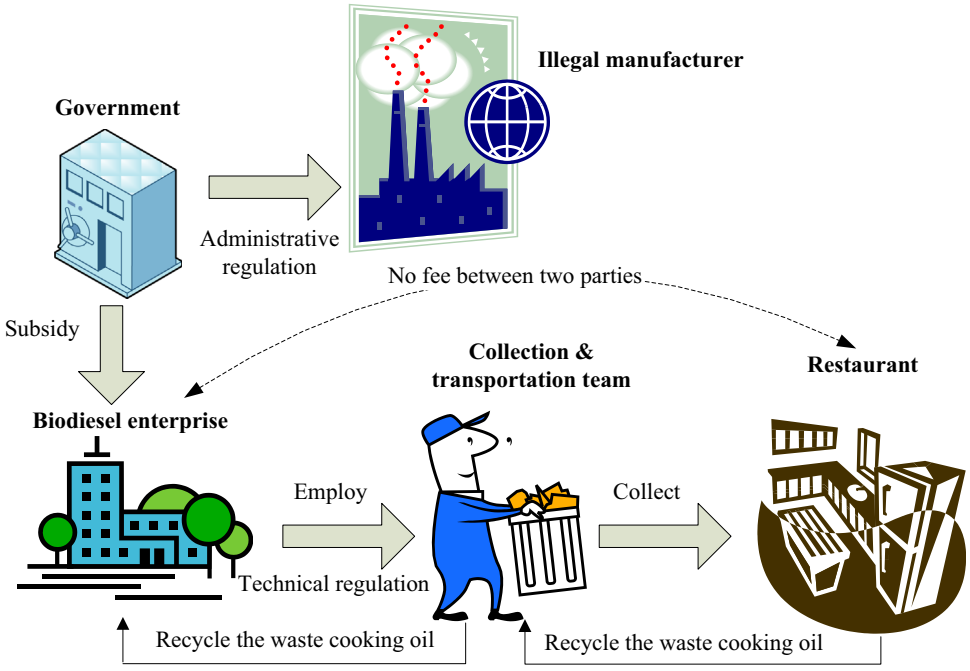


**Fig. 2.** The Suzhou case.

of waste oil being transported changes en route, it is easily detected. Finally, technology standards are set, such as waste water and residue discharge requirements in the production process of the biodiesel enterprises.

Third, in Suzhou, biodiesel enterprises are also stimulated via a system that helps minimize total costs for the supply chain. To reduce the high collection and transportation costs, Suzhou government provides subsidies to biodiesel enterprises at 118.8 yuan/ton. In addition, the fact that, biodiesel companies internalized waste cooking oil collection and transportation eliminates the transaction costs that would have existed between the enterprises and the restaurants.

Finally, restaurants in Suzhou are rewarded by a zero fee system that is in place. The central government in China requires restaurants to pay garbage disposal fees; hence restaurants try to make up for the profits lost by selling the waste cooking oil to illegal manufacturers. However, Suzhou government formulates policies to ensure that the restaurants provide the waste cooking oil to the resource recovery enterprises free of charge. In order to make up for lost revenues, the government rewards the restaurants.

Although in Suzhou waste cooking oil to biodiesel conversion is rewarded by the government, a lack of severe penalty mechanism for the restaurants illegally selling waste cooking oil results with loss of revenues for the biodiesel enterprises. A penalty mechanism may include heavy fines, establishing a close relationship between the hotel star ratings, which also assesses the quality of on-site restaurants, and the recycling of waste edible oil, etc. In addition, the supply chain incentives provided needs to be improved. Upstream of the supply chain, the incentives for the restaurants are limited. In addition, a more effective natural gas compensatory mechanism, which has been in the works for a long time by the Suzhou government, has not yet been implemented. If this policy is implemented, restaurants will be rewarded via natural gas based on their donations of waste cooking oil. Downstream of the supply chain, the biodiesel products do not sell well due to lack of incentive policies, such as providing reduced sales tax for biodiesel products.

#### 4.1.2. *The Ningbo case*

The main characteristics of Ningbo case are apparent in government guidance, legal management, centralized collection and transportation, professional disposal, public participation and market-oriented operation (Fig. 3).

Ningbo government issued *the Measures of Ningbo Municipality for Kitchen Waste Management* to regulate kitchen waste processing. According to these *Measures*, “large” restaurants can collect and

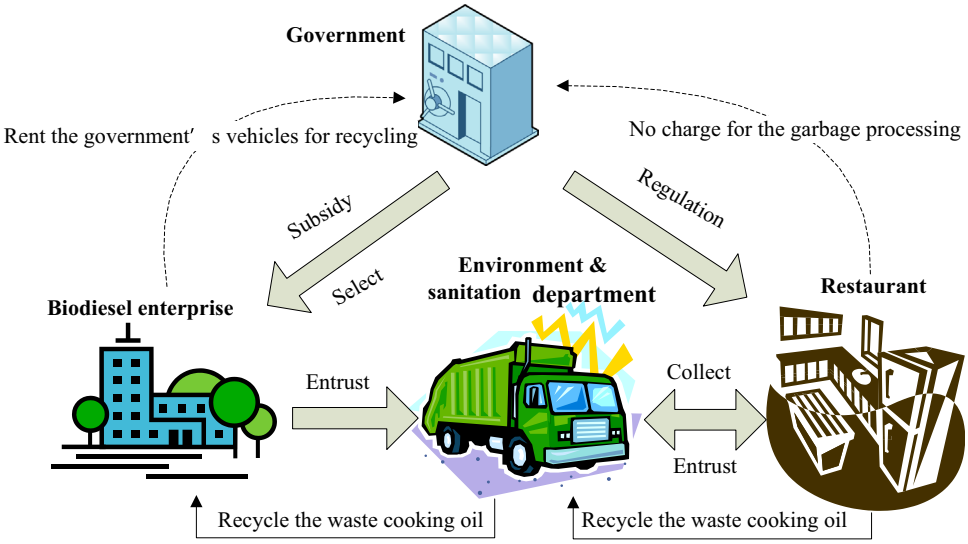


**Fig. 3.** The Ningbo case.

transport their kitchen waste independently, while other restaurants shall entrust the "urban environment and sanitation management" organization to collect and transport the kitchen waste and pay fees in accordance with the provisions. The entrusted organization shall timely collect the kitchen waste and transport them to the processing units approved by the municipal bureau for urban administration. The government's guiding function is as follows:

(1) Select three professional enterprises for the waste oil disposal through a bidding process and provide subsidies.
(2) The government provides the recycling transportation vehicles. In other words, the government purchases the kitchen waste transportation vehicles and rents them to the enterprises. Centralized collection and transportation means that the environmental sanitation departments in different districts are responsible for organizing collection and transportation. In addition to the bidding system in place, the government also reduces the transportation fees paid by the restaurants and provides free trash bins.

Obviously, even if there is an environment and sanitation department responsible for recycling, in Ningbo the mode used is a BET mode in essence. This is because the waste cooking oil is still processed by the biodiesel enterprises and not the government entity in charge of transportation. Furthermore, without the third-party recyclers, Ningbo case is effective in processing kitchen waste and recycling costs are low. Considering that there are three distinct biodiesel enterprises that end up being awarded the rights to recycling, the oligopolistic position can also effectively reduce the cost of negotiations. However, compared with the Suzhou case, Ningbo case lacks the technical regulation and the incentives mechanism for the restaurants. In the Suzhou case, each kitchen waste recycling vehicle is equipped with a GPS device and a weighing system to monitor the transportation of waste cooking oil. In addition, in the Suzhou case, the restaurants are not required to pay the kitchen waste processing fees and transportation fees. They can even be rewarded with natural gas as an incentive in the future. In the Ningbo case, the restaurants are still required to pay the transportation fees, thus reducing the possibility of channeling of waste cooking oil to the biodiesel enterprises.

#### 4.1.3. *The Lanzhou case*

In the Lanzhou collection system, the government treats the resource recovery of kitchen waste as a franchise program and provides the franchise management right to a company using a Build–Operate–Transfer (BOT) model. This company becomes responsible of investing in the construction of the resource recovery program of kitchen waste (see Fig. 4). Lanzhou government implements strict administrative and technical regulation policies. It periodically cracks down on illegal recyclers and requires restaurants to sign a contract with a biodiesel enterprise in order for them to pass the annual examination. In the Lanzhou case, the biodiesel enterprises also equip kitchen waste collection and transport vehicles with GPS devices and other communication systems that are monitored by the dispatch centers of the factories. Further, R&D is stimulated via cooperation with domestic and foreign research institutes like GanSu Academy of Sciences, European Bioenergy Research Institute, etc. These investments effectively enhance innovation along with improving productivity.

The market-oriented operation mode of BOT can also stimulate biodiesel enterprises. In the concession period, the biodiesel enterprises are responsible for the project design, financing, construction and operation. They recover the costs, repay their debts and make profits. At the end of the concession period, they hand over the project to the government. Since the government promises to grant subsidies, this case can reduce operation costs for the biodiesel enterprises and stimulate production. Despite its advantages in theory, the implementation moves at a slow pace. The government's subsidies fail to be delivered, leading to an increase in purchasing costs for the biodiesel enterprises. In addition, the government focuses on technical control and illegal recycler regulation at the transportation stage but ignores to establish a strict penalty mechanism for the restaurants that violate the law. The restaurants are required to pay for waste cooking oil processing, and without an incentive mechanism, they sell the kitchen waste to illegal manufacturers. Consequently, Lanzhou has an insufficient supply of waste cooking oil for the biodiesel enterprises and a low recycling rate.

### 4.2. *The third party take-back mode (TPT mode)*

#### 4.2.1. *The Nanjing case*

In Nanjing recyclers are stand-alone entities separate from the biodiesel enterprises (Fig. 5). In this case, third party providers establish a recycling network and staff it, and biodiesel enterprises do not directly participate in the recycling of the waste cooking oil. The advantage of the Nanjing collection system is that the third-party recyclers can benefit from their technical and network

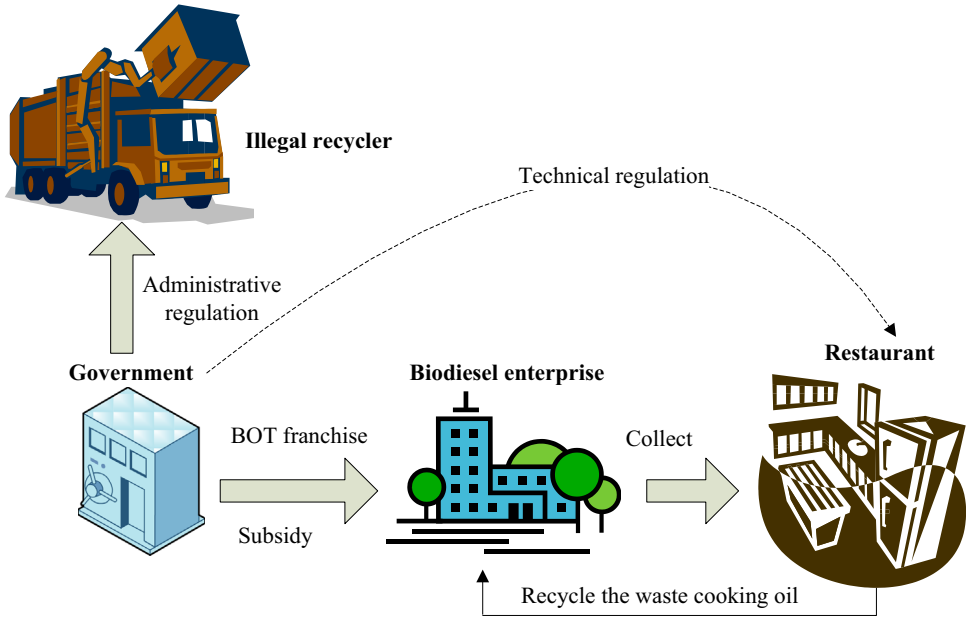


**Fig. 4.** The Lanzhou case.

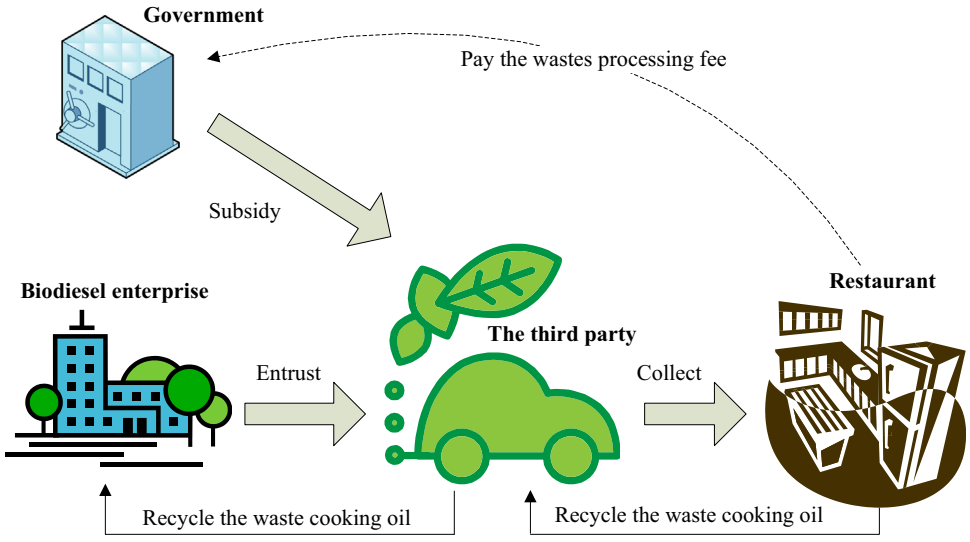


**Fig. 5.** The Nanjing case.

advantages to provide the collection services and potentially reduce the collection costs for the entire supply chain.

Nevertheless, this waste cooking oil to biodiesel conversion system is not without its shortcomings. First, the asymmetric information between the biodiesel enterprises and the recyclers may cause an increase in the purchasing costs for the former. As the biodiesel enterprises do not directly contact the restaurants, the recyclers may inflate the costs of recycling the raw material. Secondly, the recyclers may sell the waste cooking oil to illegal manufacturers, thus further exacerbating the lack of supply for the biodiesel companies. Finally, the subsidies for the third parties vary with the recycling volume. This leads to the third parties focusing on quantity rather than quality for the purpose of being subsidized. Moderate government subsidies are necessary for reducing the costs for the biodiesel enterprises and stabilizing the raw material supply. However, in practice, the Nanjing government provides subsidies to the recyclers instead of the biodiesel enterprises, and the subsidy level depends on the recycling volume. As a result, the recyclers inflate the weight of the kitchen waste in order to receive more subsidies, which seriously impacts the quality of the biodiesel produced.

#### *4.2.2. The Japanese case*

In the Japanese case, the stakeholders include the biodiesel enterprises, restaurants, the government and the transportation enterprises. The biodiesel enterprises are separate from the transportation enterprises (Fig. 6).

Despite its similarity to the Nanjing case, the Japanese collection system equips the oil–water separation device in the recycling process of the waste cooking oil, implements strict technical regulation measures and grants subsidies to the biodiesel enterprises. The Japanese restaurants usually install filters and devices to separate food waste and waste cooking oil from water, avoiding the flow of waste into the sewer and to the illegal manufacturers.

In terms of policies implemented, Japan has a strict penalty mechanism in place for sale of waste cooking oil to illegal manufacturers, which includes bankrupting the enterprises involved in it.

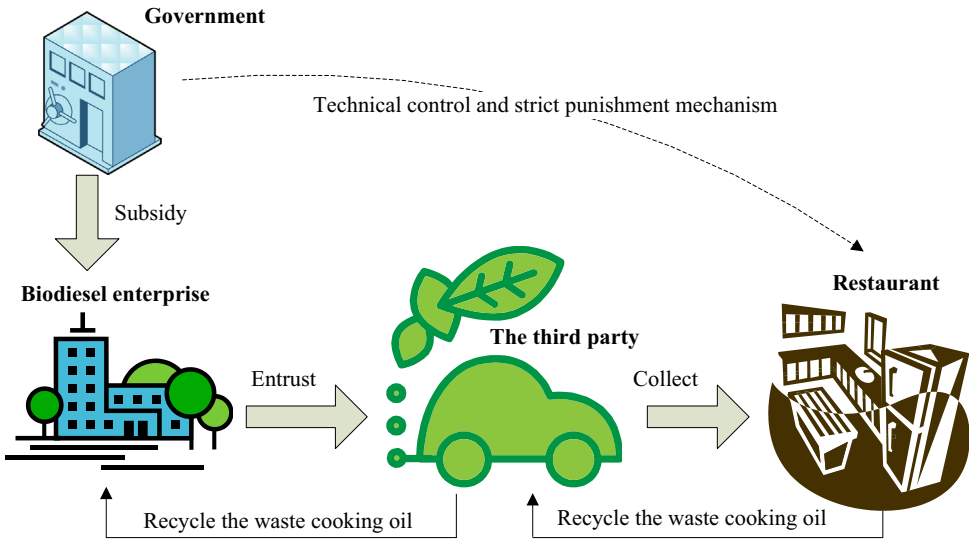


**Fig. 6.** The Japanese case.

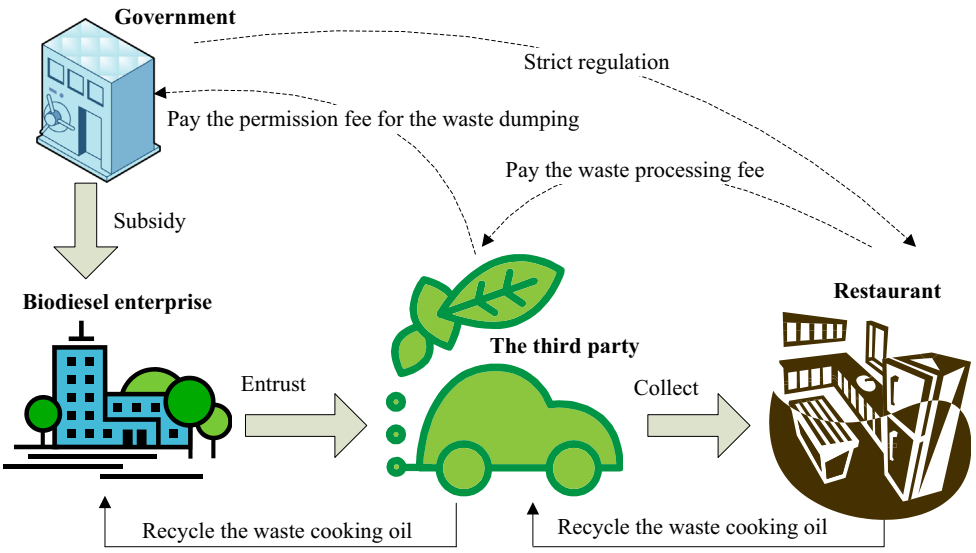


**Fig. 7.** The US case.

Waste cooking oil discharged by the restaurants must be placed in designated containers after cooling and filtering, and then recycled by a licensed third party or a biodiesel enterprise. The restaurants discharging the waste cooking oil must contract third party providers and processing enterprises at the same time. During the entire discharging process, the restaurants must ensure the quality/purity of waste cooking oil i.e. it is not mixed with water or other objects. As for the subsidy policy in place, in Japan funds are appropriated to provide subsidies to the biodiesel enterprise, which boosts their purchasing power and makes them more competitive against the illegal processing enterprises. This is different from the Nanjing case.

#### 4.2.3. *The US case*

Similar to the Japanese case, the US case also includes four stakeholders i.e. the biodiesel enterprises, restaurants, the government and the waste oil collection companies (the third party). The waste cooking oil is recycled by biodiesel enterprises that are separate from the recyclers. Unlike the former two cases listed under TPT, in the US, the restaurants are responsible of processing the kitchen waste, that is, they pay the waste recycling companies for processing. In order to obtain a permit for waste dumping, the waste oil collection companies are required to pay the fees as determined by the government (see Fig. 7). In addition, upstream of the supply chain, the federal government implements strict control measures such as a health rating scale for the restaurants. Finally, the biodiesel enterprises can receive moderate price subsidies and take advantage of tax benefits.

### 4.3. *Comprehensive comparison of six recycling cases*

Six cases presented are compared from the perspectives of recycling costs of the biodiesel enterprises, subsidy mechanisms, recycling efficiency, degree of administrative regulation, and technical support (Table 2).

In terms of recycling costs and subsidy mechanisms in place, the biodiesel enterprises, in Suzhou, Ningbo and Lanzhou cases, can obtain subsidies from the government and avoid negotiating prices with third-party recyclers, thus greatly reducing the recycling cost. However, in practice, the government has difficulties in providing the subsidies promised in the Lanzhou case, and this is inferior to Suzhou and Ningbo cases where the local governments

**Table 2**
Comparison of 6 recycling cases.

| | BET | | | TPT | | |
|---|---|---|---|---|---|---|
| | The Suzhou case | The Ningbo case | The Lanzhou case | The Nanjing case | The Japanese case | The US case |
| Recycling cost of the biodiesel enterprises | Low | Low | Middle | High | Middle | Middle |
| Whether the biodiesel enterprises obtain the subsidies or not | Yes | Yes (the transport fee paid by the restaurants) | No (not implemented by the government in practice) | No | Yes | Yes |
| Degree of the administrative control | Low | Middle | Middle | Low | High | High |
| Technical regulation and support | Strong | Weak | Strong | Weak | Strong | Strong |
| Incentive mechanism for restaurants | Yes (rewards, natural gas) | Yes (no charge for the waste disposal) | No | No | No | No |
| Recycling rate | Middle | Middle | Low | Low | High | High |
| Profits of the biodiesel enterprises | Middle | Middle | Low | Low | High | High |

provide the subsidies successfully. In the Japanese and the US cases, although the governments grant subsidies to the biodiesel enterprises, due to separation of biodiesel enterprises and the recyclers, the asymmetric price information causes an increase in transaction costs. In the Nanjing case, the biodiesel enterprises receive no subsidies from the government. In addition, they have to negotiate with recyclers, resulting in the highest recycling costs amongst all cases reviewed.

From the perspective of administrative regulation, both Japan and the US implemented strict controls on restaurants. It would benefit China to emulate these regulations. For instance, the US implements sanitary licensing, periodic supervision, risk classification management and restaurant rating evaluation systems. In addition, Resources Conservation & Recovery Act developed by the federal government allows action to be taken on the most serious offenders and penalties range from fines to prison sentences. In contrast, regulations put forth in the *Measures for the Supervision and Administration of Food Safety in Catering Services* and other regulations in China, the measures are vague and difficult to enforce. Moreover, penalties outlined in the Administrative *Measures for the Licensing of Catering Services* and the *Measures for the Supervision and Administration of Food Safety in Catering Services* issued by the Chinese government are not as strict as they should be. Of the four recycling cases reviewed in China, Lanzhou and Ningbo collection systems have a higher degree of control. In Lanzhou the government implements a strict policy of cracking down on illegal recyclers and makes passing the annual examination for restaurants conditional on having contractual relations with biodiesel enterprises. In Ningbo, the government implements a hotel sanitation rating system that also assesses the quality of the on-site restaurants, and hence regulates the restaurants and sanitation department. Despite these strict controls in place, there are still restaurants that sell waste cooking oil to illegal manufacturers, which is most likely due to the fact that an incentive mechanism and a strict penalty mechanism are not in place. In Suzhou, the government pays attention to combating of illegal manufacturers but lack regulations in supervising the restaurants. By contrast, due to lack of regulations on third parties and restaurants, Nanjing government has the weakest administrative control.

The US, Japan, Suzhou and Lanzhou governments pay attention to R&D, and improving the quality of the finished goods and/or the recycling rate; however, Nanjing and Ningbo governments do not provide strong technical support. As for incentive mechanisms in place for restaurants, only Suzhou and Ningbo governments implement it. Besides, Suzhou provides monetary rewards as well as a natural gas compensatory mechanism to the restaurants, though the latter is still not fully implemented.

In terms of the recycling rates and profits generated by the biodiesel enterprises, due to strict control and rewards mechanism, the US and Japanese cases have high recycling rates and biodiesel enterprises can be very profitable. For instance, the recycling rate in the US reaches 100 percent [29]. In contrast, in the four Chinese cities reviewed the recycling rates are much lower than in the US and Japan. For example, the recycling rate in Nanjing is less than 50 percent [30]. Some enterprises such as Jiangsu Qingjiang Bioenergy Technology Co., Ltd. even had to shut down due to financial losses endured.

When we compare the BET mode and TPT mode as they are implemented in China, US and Japan, we observe the following. BET is superior to TPT as a whole with respect to recovery costs of biodiesel enterprises and in terms of the incentives provided for the restaurants. In terms of whether the biodiesel enterprises are subsidized or not, the differences between BET and TPT are minor; however, the subsidies provided under the TPT mode are significantly higher than those under the BET mode. For instance, the subsidy rates for the biodiesel enterprises are 0.24 percent in Suzhou; while in Japan, the price of biodiesel sold to the government is 88 yen of which 1.5 yen constitutes the recovery costs of waste oil [31]. Obviously, the subsidy rate difference between the Japanese and Suzhou cases are striking. As for the administrative control, in implementation of the TPT mode (except for the Nanjing case), strict regulations are in place, which is not the case in cities where BET mode is used. The stronger subsidy mechanism and administrative controls result in higher recycling rates and profitability under the TPT mode in the US and Japan.

## 5. Policy implications

When waste cooking oil recycling modes are compared, it is observed that the recycling rates and profitability of biodiesel enterprises under TPT in the US and Japan are superior to those cities in China regardless of the mode used. Suzhou and Ningbo internalize recyclers to avoid negotiation costs, and moreover, in these two cities economic incentives are provided to the restaurants. Thus, they are superior to the cases presented in the US and Japan in these two aspects. If further enhanced, the BET mode as it is practiced in Suzhou and Ningbo cases may be superior to the TPT mode. The policy implications and recommendations are as follows:

(1) *Improving the technical support provided and regulations in place*. The measures that can be implemented include equipping collection and transportation vehicles with GPS devices and weighing systems, setting up environmental standards for

kitchen waste disposal, and cooperating with R&D institutions, universities and other enterprises to develop technologies for efficient biodiesel production.

(2) *Developing strict penalty mechanisms for restaurants*. It is suggested that, in China, penalties in *Administrative Measures for the Licensing of Catering Services and Measures for the Supervision and Administration of Food Safety in Catering Services* are further strengthened. In addition, restaurants should be held responsible for not appropriately disposing the waste cooking oil by linking this with restaurant ratings. Further, an inspection system can be implemented to identify those restaurants that violate the law.

(3) *Setting up a compensatory mechanism for restaurants*. The mechanisms can be based on cash incentives, tax benefits, energy consumption subsidies, etc.

(4) *Doing away with the kitchen waste disposal fee system*. This can result in an increase in restaurants' willingness of working with biodiesel enterprises and improve the recycling rates.

(5) *Reforming the subsidy system*. The subsidies can be provided to biodiesel enterprises instead of providing it to the third party enterprises to enhance the competitiveness of the biodiesel companies against illegal manufacturers.

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## References

[1] Jiang XJ. What made the professor who had uncovered waste cooking oil changed his tune? China Youth Daily; 24 March 2010.
[2] National Development and Reform Commission. National Development and Reform Commission, the Ministry of Finance, the Ministry of Housing and Urban Construction: determine the first 33 pilot cities (district) of kitchen waste recycling and harmless disposal [EB/OL]. 〈http://www.sdpc.gov.cn/xwfb/t20110802_426971.htm〉.
[3] Savaskan RC, Bhattacharya S, Van Wassenhove LN. Closed-loop supply chain models with product remanufacturing. Manag Sci 2004;50(2):239–52.
[4] Savaskan RC, Van Wassenhove LN. Reverse channel design: the case of competing retailers. Manag Sci 2006;52(1):1–14.
[5] Liu XF, Chen T, Liu JM, Zhang HB. ANP-based evaluation for the selection of recovery modes in reverse logistics. J Univ Electron Sci Technol China (Soc Sci Ed) 2007;9(3):32–5.
[6] Xu B, Wu M. Modeling analysis on the three recovery modes of dual channel closed-loop supply chain. Math Pract Theory 2012;42(11):10–9.
[7] Wei J, Li J. Selection of recovery modes in reverse logistics with the restrictions of EPR. Chin J Manag Sci 2005;13(6):18–22.
[8] Senthil S, Srirangacharyulu B, Ramesh A. A decision making methodology for the selection of reverse logistics operating channels. Procedia Eng 2012;38:418–28.
[9] Majumder P, Groenevelt H. Competition in remanufacturing. Prod Oper Manag 2001;10(2):125–41.
[10] Cheng YH, Lee F. Outsourcing reverse logistics of high-tech manufacturing firms by using a systematic decision-making approach: TFT-LCD sector in Taiwan. Ind Mark Manag 2010;39:1111–9.
[11] Azadi M, Saen RF. A new chance-constrained data envelopment analysis for selecting third-party reverse logistics providers in the existence of dual-role factors. Expert Syst Appl 2011;38:12231–6.
[12] Govindan K, Palaniappan M, Zhu QH, Kannan D. Analysis of third party reverse logistics provider using interpretive structural modeling. Int J Prod Econ 2012;140:204–11.
[13] Wang X, Chen M. Implementing extended producer responsibility: vehicle remanufacturing in China. J Clean Prod 2011;19:680–5.
[14] Johnson MR, McCarthy IP. Product recovery decisions within the context of extended producer responsibility. J Eng Technol Manag 2013,http://dxdoi.org/〈10.1016/j.jengtecman.2013.11.002〉.
[15] Tsay AA. Management retailer channel overstock: markdown money and return policies. J Retail 2001;77(4):451–92.
[16] Zhou YS, Wang SY. Calling back EOL products under the supervision of the government. Syst Eng – Theory Pract 2010;30(4):615–21.
[17] Wang WB, Da QL. The decision-making model of collection and remanufacturing of electronic product manufacturer under the premium and penalty mechanism. Chin J Manag Sci 2008;16(5):57–63.
[18] Wang WB, Da QL. Analysis on premium and penalty mechanisms for the electronic product reverse supply chain considering the guidance of Government. Chin J Manag Sci 2010;18(2):62–7.
[19] Wang L, Liu YZ. Classificatory model for urban food waste recycling and disposal. J Northwest A&F Univ (Soc Sci Ed) 2009;9(3):110–4.
[20] Zhang YM, Huang GH, He L. An inexact reverse logistics model for municipal solid waste management systems. J Environ Manag 2011;92:522–30.
[21] Ramos TRP, Gomes MI, Barbosa-Póvoa AP. Planning waste cooking oil collection systems. Waste Manag 2013;33:1691–703.
[22] Kelloway A, Marvin WA, Schmidt LD, Daoutidis P. Process design and supply chain optimization of supercritical biodiesel synthesis from waste cooking oils. Chem Eng Res Des 2013;91:1456–66.
[23] Kagawa S, Takezono K, Suh S, Yuki Kudoh. Production possibility frontier analysis of biodiesel from waste cooking oil. Energy Policy 2013;55:362–8.
[24] Lam HL, Ng Wendy PQ, Ng Rex TL, Ng Ern Huay, Abdul Aziz Mustafa K, Ng Denny KS. Green strategy for sustainable waste-to-energy supply china. Energy 2013;57:4–16.
[25] Tsai WT, Lin CC, Yeh CW. An analysis of biodiesel fuel from waste edible oil in Taiwan. Renew Sustain Energy Rev 2007;11:838–57.
[26] Zhang HM, Wang QW, Mortimer SR. Waste cooking oil as an energy resource: review of Chinese policies. Renew Sustain Energy Rev 2012;16(7):5225–31.
[27] Liang S, Liu Z, Xu M, Zhang TZ. Waste oil derived biodiesels in China bring brightness for global GHG mitigation. Bioresour Technol 2013;13:139–45.
[28] Zhang HM, Li LH, Zhou P, Hou JM, Qiu YM. Subsidy modes, waste cooking oil and biodiesel: policy effectiveness and sustainable supply chains in China. Energy Policy 2014;65:270–4.
[29] Hao JX. Waste cooking oil in the US: recycling once a week. 13 November 2012.
[30] Zhao SC, Zhao DD. More than a half of waste oil is missing in Nanjing. Mod Express; 15 September 2011.
[31] Sa S. How to keep the waste cooking oil away from dinner tables in Japan. Bus Stories; 15 September 2010.